PROGRESS REPORT OF CNES ACTIVITIES REGARDING THE ABSOLUTE CALIBRATION METHOD

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Abstract

Global Navigation Satellite System (GNSS) time and frequency transfer is among the most useful tools for comparisons of remote clocks. It represents the basis of the time laboratories contributions for the realization of Temps Atomique International (TAI). The GNSS reception chains (antenna, antenna cable, geodetic receiver), used currently to perform the time comparisons, must be calibrated periodically to ensure their accuracy and their long-term stability. The most widely approach used to determine the electrical delay and the time stability of these chains is the differential method developed by the BIPM.

Since 2005, CNES (French Space Agency) has developed the absolute calibration, using artificial signals, which opens the possibility to calibrate independently each element of the reception chain with a low uncertainty. The time-delay uncertainties of receiver and cable are respectively about of 0.40 ns and 0.050 ns for k=1. Recently, our efforts have mainly focused on the behavior of several receivers (Ashtech Z12-T, Septentrio PolaRx2, and Dicom GTR50) and a GNSS signal simulator (Spirent 4760) according to the temperature and the hygrometry variations. The first results of this study have been presented during the last EFTF meeting. At the present time, we have a good comprehension of the behavior of investigated receivers and the simulator according to the environment where they are located. Since 2009, the absolute calibration investigations have mainly concerned the last element of the reception chain, the GNSS antenna.

Through this paper, we give a progress report of the CNES activities relating to the absolute calibration. First of all, it displays the variations of the internal electrical delay of some devices (several receivers and a simulator) according to the temperature, the hygrometry, and the aging. The antenna calibration procedure is then described.

INTRODUCTION

The GNSS reception chains (GPS dual frequency receiver + antenna + antenna cable) are used to perform time comparisons of remote atomic clocks for the TAI (Temps Atomique International) calculation.

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14. ABSTRACT
Global Navigation Satellite System (GNSS) time and frequency transfer is among the most useful tools for comparisons of remote clocks. It represents the basis of the time laboratories contributions for the realization of Temps Atomique International (TAI). The GNSS reception chains (antenna, antenna cable, geodetic receiver), used currently to perform the time comparisons, must be calibrated periodically to ensure their accuracy and their long-term stability. The most widely approach used to determine the electrical delay and the time stability of these chains is the differential method developed by the BIPM.

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They are now standard equipment of operational units in a time laboratory. The calibration of these chains are necessary to ensure accuracy and long-term stability of time links used in TAI, but also in a precise time station (PTS) dedicated to GALILEO.

Currently, the most widely used approach to determine the electrical delay of these devices is the differential method developed by the BIPM. This technique consists in co-locating a reference chain with a laboratory chain to calibrate it (short-baseline experiment). The reference equipment is in permanent circulation among timing laboratories. A relative calibration is performed between this equipment and the laboratory equipment **[1]**.

Another solution is the absolute calibration of each reception chain element in using artificial signals. This method was first defined and performed by the University of Colorado and put into operation by the Naval Research Laboratory (NRL) **[2]**. In 2005, CNES decided to develop this technique with a similar approach.

The first section summarizes the CNES activities' advancements regarding the absolute calibration. The methods currently used by CNES to calibrate each element of the time transfer system are then described. A precise uncertainty budget is given for each calibration in order to finally determine the global uncertainty of the reception chain calibration. The final part of this paper is dedicated to the investigations of the receivers' (Ashtech and Septentrio) sensitivity to the environment parameters temperature, hygrometry and time.

PROGRESS REPORT OF CNES ACTIVITIES

Since 2005, CNES (French Space Agency) has developed the absolute calibration with a similar approach to the technique put into operation by NRL. It consists in calibrating independently the antenna, the cable, and the receiver.

One of principal differences between NRL's and CNES's absolute methods is the way of calibrating the signal simulator used in the receiver calibration (Spirent4760). The internal delay of the simulator corresponds to the delay between the beginning of the PRN C/A code and the internal one pulse per second (PPS) synchronized with the GPS time. In amplifying a single-channel C/A code, the time difference between the rising 1PPS and the code transition can be measured with an oscilloscope **[3,4]**.

The NRL method consists of determining the time difference by direct reading (Tick-to-Code). The measurement error with this method is about 0.2 ns **[3]**. The CNES method is based on a post-treatment applied to the oscilloscope acquisitions. This method allows one to improve the simulator calibration because the time delay is estimated over more than one code transition. The technique used is the correlation, which looks like a standard GPS signal acquisition. It consists of determining the code offset versus the PPS generated by the simulator and the residual carrier phase offset. The two parameters are evaluated simultaneously to determine the internal delay simulator. The measurement uncertainty is the integration time of the correlation, which is equivalent to the oscilloscope resolution **[4]**. The fast digital oscilloscope used has a resolution of 0.1 ns, which will be, therefore, the accuracy of the correlation method.

The first CNES absolute calibrations of a receiver were performed with an Ashtech Z12-T with an uncertainty of 0.88 ns for the L1 frequency and of 2.37 ns for the L2 frequency. Progress on the receiver absolute calibration allows improvement of the calibration method and the uncertainty budget. Indeed, in

2008 the calibrations of an Ashtech and a Septentrio receiver were performed with an uncertainty about 0.4 ns (k=1) **[5,6]**.

During the study of the receivers' calibration, acquisitions of several days showed pseudo-range fluctuations of about 0.4 ns/K (k=1) **[5,6]**. It becomes important to understand the equipment comportment with the temperature variations. A first study of the equipment thermal sensitivity has allowed us to estimate **[5]**:

- the linearity of the simulator thermal sensitivity: 0.12 ns/K to 0.3 ns/K (k=1) for [289-300 K]
- the linear sensitivity of the Ashtech receiver: 0.15 ns/K (k=1) for [273-313 K] previously observed by the Royal Observatory of Belgium **[7]**
- the nonlinear sensitivity of the Septentrio receiver: 0.2 ns/K to 0.02 ns/K (k=1) for [278-313 K].

Moreover, CNES activities proved that most of geodetic receivers used in time laboratories, Ashtech Z12-T, Septentrio PolaRx2, and Dicom GTR50, can be calibrated with the absolute method **[6,8]**.

The last works concerned the setup of the antenna calibration and the equipment behavior functions of the environment. The first investigations of the antenna calibration were performed with the method in transmission using a Vector Network Analyzer (VNA). The first results give an uncertainty about 0.45 ns (refer to section Antenna Calibration). A detailed study of the time delay equipment behavior according to the environment variations (temperature and hygrometry) allows one to explain the pseudo-range fluctuations observed (refer to Equipment Behavior versus Environment Parameters).

ABSOLUTE CALIBRATION METHOD

The absolute calibration method consists of determining the electrical delay of each element of the reception chain in an independent manner. This section presents the technique used by CNES to calibrate radiofrequency (RF) cable, receivers, and antennas. A detailed uncertainty budget will be presented for each calibration technique.

ANTENNA CABLE CALIBRATION

The calibration of the antenna cable consists of measuring the signal transmission time through the test device. This measurement, called group delay (τ), is defined as the derivative of the phase with respect to frequency (Eq.1).

$$Group\ \ delay = \frac{-1}{360^\circ}\frac{d\phi}{df} \qquad \text{Eq. 1}$$

- dϕ: Phase derivative [deg]
- df :Frequency derivative [Hz]

A VNA is employed to measure the signal propagation time. To decrease the measurement uncertainty, VNA parameters such as the aperture, the IF bandwidth, the frequency band, and the number of points were optimized. Figure 1 illustrates the group delay of an LMR400 antenna cable of 50 meters in the range of 1.1 GHz to 1.6 GHz.

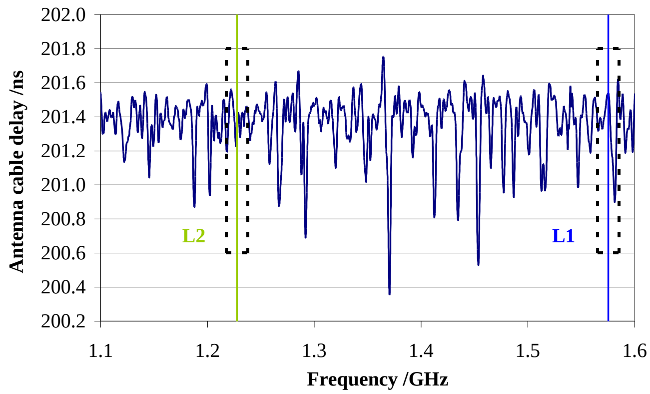

Figure 1. An LMR400 cable (50 m) delay measurement.

In this case, the group delay exhibits important variations because the cable is longer than the antenna cable generally used and was deteriorated during a European differential calibration campaign managed by the LNE-SYRTE.

The cable delay corresponds to the average of the acquisitions in a frequency band equivalent to the GNSS signal bandwidth centered around the studied frequencies.

If adapters are added to the cables' extremities, the uncertainty of the adapters' measurement must be taken into account in the calculation of the final uncertainty budget. The uncertainty of a 50-meter cable is 0.19 ns (k=1). The sources of uncertainty in this measurement are summarized in Table 1.

Table 1. Uncertainty of an LMR400 antenna cable (50 m) calibration.

Source Uncertainty	L1/L2 [ns] (k=1)
Vector Network Analyzer	0.17
Acquisition standard deviation	0.09
Adaptors measurement	0.03
u (Antenna cable)	***0.19***

The overall uncertainty is the quadratic sum of the uncertainty sources. The VNA uncertainty is made up of the phase and frequency error. The acquisition standard deviation is calculated for a 20 MHz bandwidth around the L1 or L2 frequencies.

Timing Receiver Calibration

The timing receivers perform pseudo-range and carrier-phase measurements which are referred to an "internal reference" derived from an external frequency signal and an associated 1PPS input. The 1PPS external signal allows the receiver to choose one particular cycle of the frequency signal to form the internal reference. This operation guarantees repeatability of this reference in case of interruption of the tracking or operation of the receiver.

The approach used to calibrate this kind of receiver consists of an artificial reception free of delays, effects, and noises upstream at the output of antenna: atmospheric delays (troposphere and ionosphere), multipath effects or antenna delay, etc. This condition can be conducted with a GNSS signal simulator. The simulator used is a Spirent STR4760. It generates pseudo-range code signals on both L1 and L2 frequencies (four channels in L1 and 4 channels in L2).
Figure 2 Figure 2 describes a schematic of receiver absolute calibration.

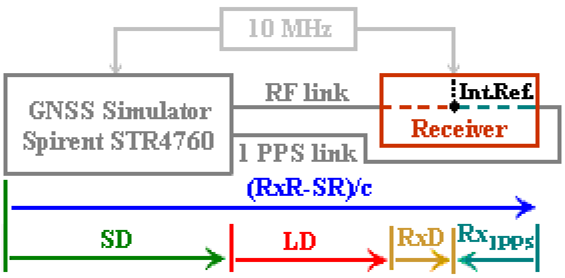

Figure 2. Schematic of receiver absolute calibration.

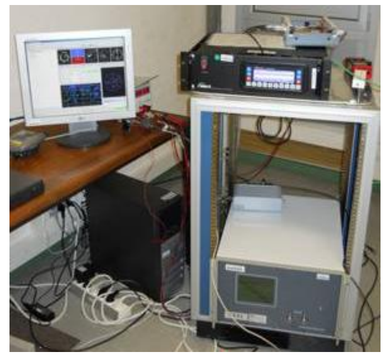

Figure 3. Receiver absolute calibration.

This fixed relationship allows the receiver delay calculation. The internal electrical time delay of the receiver is calculated thanks to the following equation (Eq. *2*):

$$RxD = \frac{RxR - SR}{c} - LD - SD + Rx_{1PPS} \qquad \text{Eq. 2}$$

where:

- **RxD:** Receiver delay [s]
- **RxR-SR:** Difference of receiver and simulator pseudo-ranges [m]
- **c:** Light celerity [m/s]
- **LD:** 1PPS and RF links delays difference (LD_{RF}-LD_{1PPS}) [s]
- **SD:** Simulator delay [s]
- **Rx_{1PPS} :** Time delay between the receiver internal reference and the external 1 PPS [s].

During the calibration measurement, due to their temperature sensitivity **[5,8]**, the simulator and the receivers were located in a room regulated to 293 K with a maximum deviation of ±1 K.

The uncertainty of the receiver delay is the quadratic sum of the measurement uncertainty of the simulator calibration, the RF and 1 PPS links, the pseudo-range differences, and the parameter Rx_{1PPS}. The uncertainty can vary from 0.37 ns to 0.43 ns (k=1) according to the kind of receiver **[6]**. This difference is due to the calculation and the measurement technique of the Rx_{1PPS} parameter, which is defined by each manufacturer.

For the Ashtech Z12-T receiver, the Rx_{1PPS} value is defined by the Tick-to-Phase, which is the time difference between the first positive zero crossing of the 20-MHz-in following the rising tick of the 1PPS-in signal **[3]**.

For the Septentrio PolaRx2 receivers, the delay between the rising tick of the 1PPS input signal and the latching of the measurements is between 221.7 and 255 ns (±2 ns) (Rx_{1PPS} : X_0). In order to measure the delay between the 1PPS input pulse and the measurement latching, it is possible to synchronize the 1PPS output signal from the receiver with the measurement latching epoch. The constant offset between the 1PPS output and the measurement latching is indicated in Septentrio PolaRx2's documentation: "measurement latching" = "Output 1PPS" plus 8.7 ns (for firmware version 2.3 and higher) **[9]**.

For the GTR50 receivers, the time difference between the 1PPS external signal and this internal time base (Rx_{1PPS}) is collected like the receiver measurement data (pseudo-ranges and phase measurements to individual satellites) in hourly files. Contrary to the previous receivers, no 1 PPS internal delay is considered and all the output data (RINEX, CGGTTS, L3P, RAW) are referenced to the external 1PPS.

The next table gives an example of uncertainty budget for Ashtech, Septentrio, and Dicom receiver calibrations.

Table 2. Uncertainty of the different receiver calibrations.

Uncertainty Source	**Ashtech L1/L2 [ns] (k=1)**	**Septentrio L1/L2 [ns] (k=1)**	**Dicom L1/L2 [ns] (k=1)**
Simulator	0.35	0.35	0.35
RF link	0.003	0.003	0.003
1 PPS link	0.003	0.003	0.003
Pseudo-ranges difference	0.13	0.14	0.16
Rx_{1PPS}	0.14	0.21	-
u (receiver)	***0.41***	***0.43***	***0.37***

The simulator uncertainty takes into account the uncertainties of RF and 1 PPS links measurement, the correlation uncertainty (oscilloscope resolution), the pseudo-ranges error, and the interchannel bias (provided by the constructor). The RF link delay is measured through a VNA with the same technique used for the antenna cable. The 1PPS link delay is determined with a time-interval counter in employing the double weight method. For the Ashtech receiver, the Rx_{1PPS} parameters are defined by the Tick-to-Phase measured with an oscilloscope. The Rx_{1PPS} uncertainty is made up of the oscilloscope resolution and the error reading. For the Septentrio receiver, the Rx_{1PPS} is measured with a time-interval counter. In this case, the uncertainty is the relative error of the equipment. It is not necessary to determine the Rx_{1PPS} for the Dicom receiver because the measurement is referenced to the external 1 PPS.

ANTENNA CALIBRATION

The antenna calibration consists of estimating the time-delay due to the signal propagation through the antenna. It will be, therefore, necessary to determine the input and output ports of the signal in the device. An antenna allows the transition of the electromagnetic wave between a guided environment (cable) and a free environment (air). One of the access ports will be defined by the access connector (BNC/TBNC/N). The other port will be defined by the phase center, which is the interface point between the guided environment and free space.

To calibrate the antennas, they are placed in an anechoic chamber (Figure 4), which is equipped with a mechanical bench containing two supports. One is mobile horizontally and vertically and the other one is fixed (Figure 5). The anechoic chamber measures about 8 m^3. The distance between the antennas can be matched up from 0 to 2 meters.

Figure 4. The anechoic chamber.

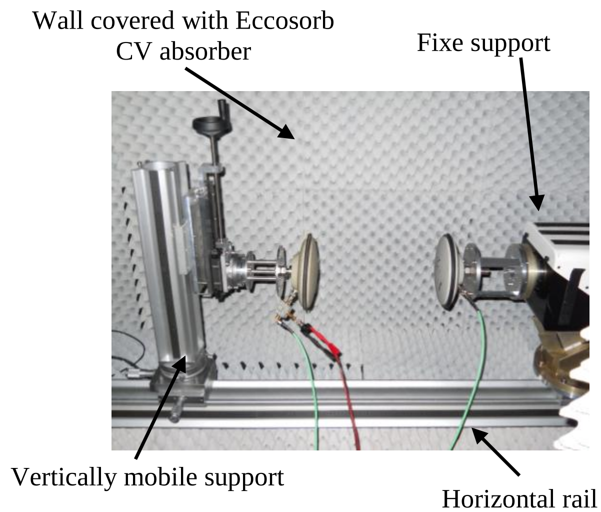

Figure 5. Mechanical supports in the anechoic chamber.

Antennas used in GNSS reception chain for the time transfer are active (included an internal amplifier) and have a Right-Hand Circular Polarization (RHCP). The amplifier does not allow the reciprocal signal crossing through the antenna. To calibrate this kind of antenna, we must use the method in transmission presented in Figure 6. The measurement of the transmission delay between both ports of a VNA allows the determination of the group delay of the antenna. The signal supplied by the VNA is transmitted by a passive antenna to the receiving antenna (element to calibrate). Then the receiving antenna sends the signal to the second port of the VNA. The antenna amplifier needs to be powered in order to properly measure its delay. Power is supplied to the receiving antenna with a DC block (not shown).

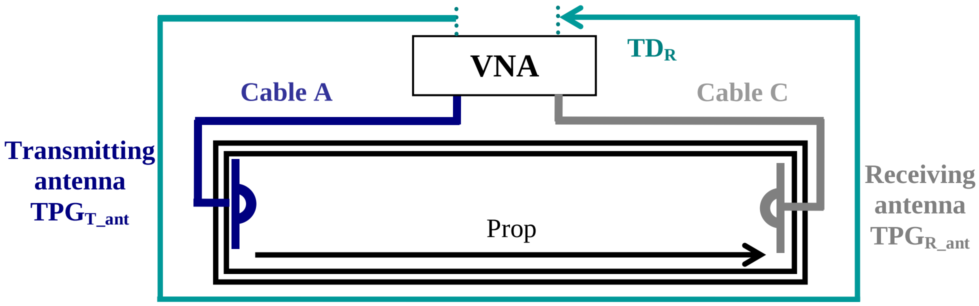

Figure 6. Antenna calibration with the method in transmission.

In using the method in transmission, the group delay of the receiving antenna is defined by the following equation (Eq. 3):

$$\tau_{R\_ant} = TD_R - \tau_A - \tau_{T\_ant} - Prop - \tau_C \qquad \text{Eq. 3}$$

- **$\tau_{R\text{-}ant}$:** Electrical delay of the receiving antenna [s]
- **TD_R:** Time delay of the transmission measurement [s]
- **τ_X:** Electrical delay of the cable X [ns]
- **$\tau_{T\text{-}ant}$:** Electrical delay of the transmitting antenna [s]
- **Prop:** Delay due to the signal crossing in the air [s].

The antenna calibration uncertainty in using the method in transmission is composed of the measurement uncertainties of the total delay, the RF links, the distance between both phase centers, and the transmitting antenna. The following table gives the uncertainty of a NovAtel 702 antenna in using a NovAtel 704-X antenna-like transmitting antenna.

Table 3. Uncertainty of antenna.

Uncertainty Source	L1/L2 [ns] (k=1)
Total delay	0.30
RF link (Cable A and C)	0.003
Propagation	0.002
Transmitting antenna	0.31
u (NovAtel 702 Antenna)	***0.45***

The uncertainty of the total delay is the standard deviation of successive acquisitions in using different bandwidths. The propagation error takes into account the variations of the phase centers and the error between both antennas. The time delay of the transmitting antenna was determined with the method in transmission with two identical antennas.

To perform the antenna calibration with the method in transmission, the delay of the transmitting antenna must be known; thus, it must be calibrated. Two methods are available to calibrate a passive antenna: the method in transmission (with two identical antennas) or the method in reflection. For a measurement in transmission, the group delay of the antenna is defined by the following equation (Eq. 4):

$$\tau_{T\_ant} = (TD_R - \tau_A - Prop - \tau_C)/2 \qquad \text{Eq. 4}$$

- **τ_{T_ant}:** Electrical delay of the transmitting antenna [s]
- **TD_R:** Time delay of the reflection measurement [s]
- **τ_X:** Electrical delay of the cable X [s]
- **Prop:** Delay due to the signal crossing in the air [s]

During a measurement in reflection, the signal supplied by the VNA and emitted by the antenna is reflected by an element placed downstream to the output port at a known distance.

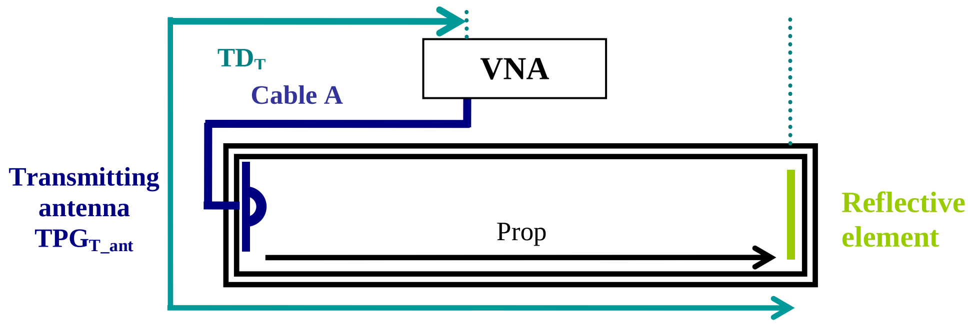

Figure 7. Antenna calibration with the method in refection.

In using the method in reflection, the group delay of the transmitting antenna is defined by the following equation (Eq. 5):

$$\tau_{T\text{-}ant} = (TD_T/2) - \tau_A - Prop \qquad \text{Eq. 5}$$

- **τ_{T_ant}:** Electrical delay of the transmitting antenna [s]
- **TD_T:** Time delay of the transmission measurement [s]
- **τ_A:**: Electrical delay of the cable A [s]
- **Prop:** Delay due to the signal crossing in the air [s].

Uncertainty Budget of the Time Transfer System Calibration

The total error budget for a GPS reception chain takes into account the source uncertainty of each element of the reception chain: the antenna cable, the receiver, and the antenna. Table 4 presents the worst uncertainty budget of the reception chain calibration . The cable used is an LMR400 cable with a length of 50 meters, the receiver used is Septentrio PolaRx2, and the antenna is a NovAtel 702.

Table 4. Uncertainty of a time transfer system.

Uncertainty Source	L1/L2 [ps] (k=1)
Antenna cable	0.19
Receiver	0.42
Antenna	0.45
u (Time transfer system)	***0.64***

The overall uncertainty of the reception chain is around 0.64 ns (k=1), in which the dominant element is the interchannel bias of the simulator. This value could be reduced by using a more recent simulator where all the signals are generated by the same chips performing so as to cancel the bias between the channels. Moreover, the follow-up of the antenna calibration study will perhaps allow the decrease of the weight of this uncertainty source.

EQUIPMENT BEHAVIOR VERSUS ENVIRONMENT PARAMETERS

Previous work on the receiver absolute calibrations show that not only the receivers, but also the simulator, are sensitive to the environment parameters. Pseudo-range fluctuations of about 0.4 ns/K have been already observed **[5,6**]. Moreover, the differential method showed differences for the calibration of the same receiver performed several times in few years **[9]**. Therefore, it becomes important to know the influence of the environment parameters (temperature, hygrometry, and aging) to explain observed variations. An experiment has been set up to determine precisely the thermal and hygrometric sensibilities of the receivers (characterized element) and of the simulator (characterization element).

The simulator (Spirent STR4760) and the studied receivers (Septentrio PolaRx2, and Ashtech Z12-T) were placed in two identical thermal chambers (Secasi SLH150) allowing independent control of the variations of the environment (temperature and humidity).

The thermal chambers enable regulation of the temperature with a precision of 0.1 K (k=1) and the humidity with a precision of 0.3% (k=1).

The thermal chamber environment of the unstudied equipment (simulator or receiver) stays stable (Temperature = 293 K, Humidity = 30%).

TEMPERATURE

Simulator

The thermal sensitivity shown the simulator has a linear temperature dependence of about 0.32 (0.02) ns/K for a temperature range of 286 to 308K (13 to 35 °C) **[8]**.

Receiver

For this study, a temperature ramp of 0.5 K/h was applied in the thermal chamber of the receiver. The humidity rate is maintained at 30%. The simulator environment will remain stable (Temperature = 293 K, Humidity rate = 30%). The thermal sensibility of the receivers will be studied in the identical temperature range of 273 K to 313 K.

A. Ashtech Z12-T (Z12-T Lab):

Figure 8 presents the variations of the Ashtech internal delay according to the temperature in a range from 273 to 313 K.

All the codes have a linear temperature dependence which is of the same order of magnitude:

- For the L1 frequency, C/A code: $\alpha_{C/A} = 0.09$ ns/K [273-313 K]
  P Code: $\alpha_{P1} = 0.11$ ns/K [273-313 K]
- For the L2 frequency, P code: $\alpha_{P2} = 0.11$ ns/K [273-313 K]

The thermal sensibility measurement of the Ashtech Z12-T receiver shows an average of 0.012 ns/K (k=1) uncertainty.

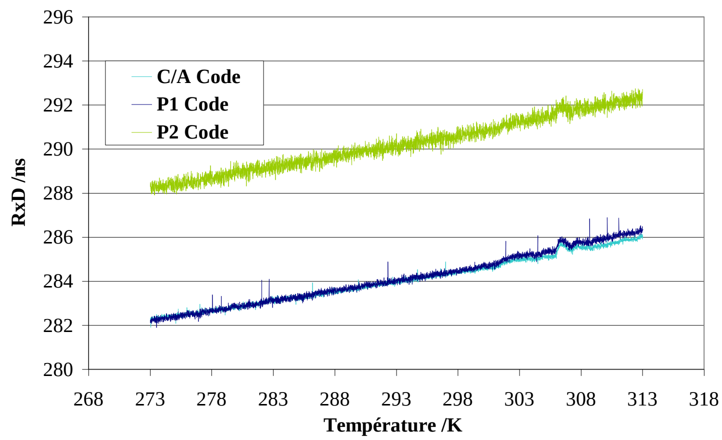

Figure 8. Ashtech internal delay versus temperature.

B. Septentrio PolaRx2 (PolaR Lab):

Figure 9 describes the variations of the Septentrio internal delay according to the temperature in a range from 273 to 313 K.

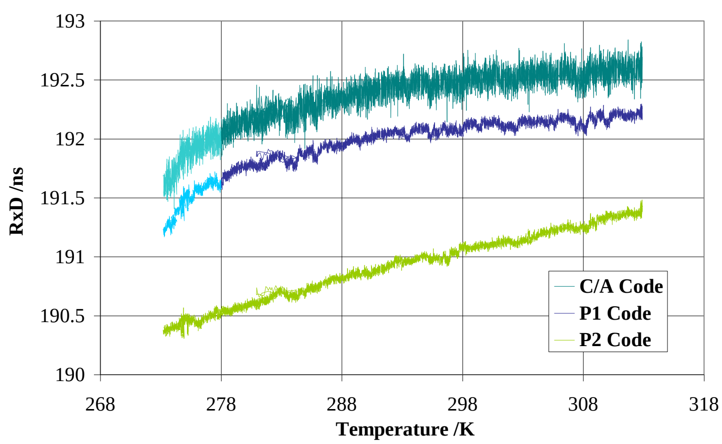

Figure 9. Septentrio internal delay versus temperature.

For the L1 frequency, the variations of the receiver internal delay increased with slope changes for the C/A code and the P code. The temperature influence is strong from 273 to 278 K; then it becomes relatively weak from 278 to 313 K. For the L2 frequency, the receiver thermal sensibility varies linearly with the temperature and is relatively low on all the studied range.

These acquisitions allow one to define the relation between the variations of the receiver internal delay and the temperature for each code:

- For the L1 frequency: $\alpha_{L1} = 0.09$ ns/K [273-278 K]
  $\alpha_{L1} = 0.01$ ns/K [278-313 K]
- For the L2 frequency: $\alpha_{L2} = 0.02$ ns/K [273-313 K]

The thermal sensitivity measurement of the Septentrio PolaRx2 receiver shows an average of 0.016 ns/K (k=1) uncertainty.

HYGROMETRY

We have also decided to evaluate the equipment hygrometric sensitivity. The chosen range is included between 20% and 70%. The temperature is maintained at 293 K. Contrary to the thermal study, where a slow ramp is applied, here the humidity is ordered to jump 50%, as shown in Figure 10. The thermal chamber environment of the unstudied equipment (simulator or receiver) stays stable (Temperature = 293 K, Humidity = 30%). In the case presented, we can see the pseudo-range fluctuations due to the hygrometric sensitivity of the simulator measured with the Septentrio receiver.

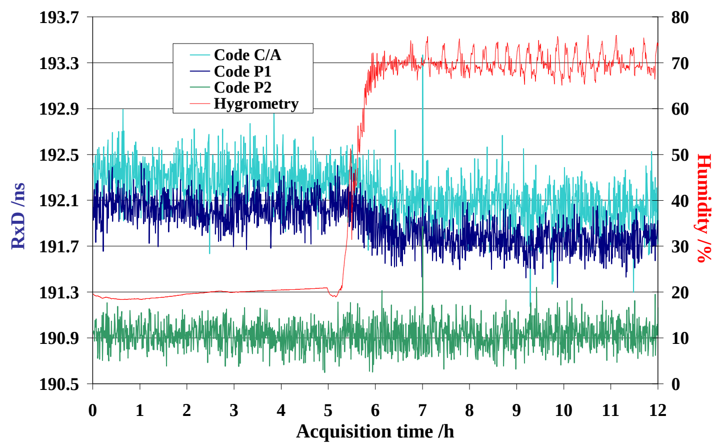

Figure 10. Receiver delay and humidity of the simulator thermal chamber versus acquisition time.

This experiment allows determination of the hygrometric sensitivity of each piece of equipment for the humidity rate. The simulator sensitivity is about 0.004 ns/% (k=1) for L1 and 0.001 ns/% (k=1) for L2. The Septentrio sensitivity is about 0.003 ns/% (k=1) for L1 and 0.002 ns/% (k=1) for L2 when the Ashtech sensitivity is about 0.001 ns/% for L1 and L2. The uncertainty is always of the same order of magnitude as 0.011 ns/%.

The variations due to the hygrometric changes are not the principal cause of the pseudo-range variations when the experiment takes place in a controlled environment. On the other hand, the humidity rate could perhaps cause variations of the pseudo-range measurement according to the geographic zone (dry: humidity rate < 20% or damp: humidity rate > 90%) where the equipment is used.

AGING

The differential method shows differences for the calibration of the same receiver performed several times in a few years **[9]**. It is, therefore, important to study the calibration variation results in the time period. Figure 11 describes the absolute calibration of the Septentrio PolaRx2 (Polar Lab) since March 2008 until the last month.

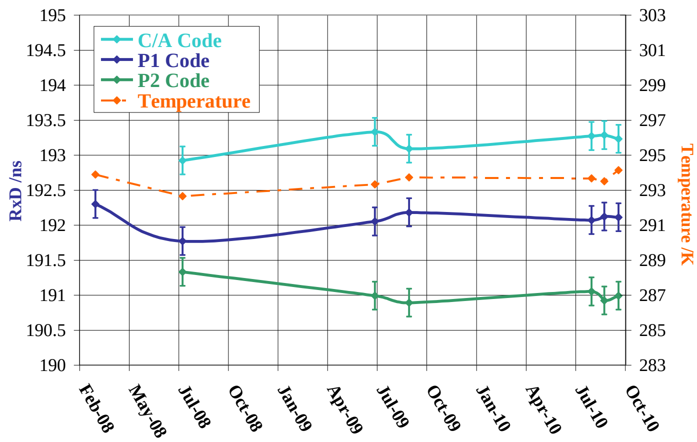

Figure 11**.** Septentrio receiver delay according to time over 2 years.

The Septentrio PolaRx2 time-delay is on average:

- C/A code : 193.19 (0.42) ns
- P1 code : 192.05 (0.42) ns
- P2: 191.03 (0.42) ns.

The calibrations of the Septentrio receiver show variations which do not exceed 0.41 ns for each code. To understand the variations, the results were compared with the room temperature. The variations of the time delay receiver seem correlated with the temperature variations rather than the effect of device aging. This experiment must be performed on the long term and on different receivers to get a relevant conclusion on the aging effect. This is a graphic reminder of the importance of the temperature during the calibration.

SUMMARY

Table 5 summarizes the thermal and hygrometric sensibilities of each piece of equipment:

Table 5. Summary of the thermal and hygrometric dependence of each piece of equipment.

Parameters	**Simulator (*STR8*)**	**Septentrio (*Polar Lab*)**	**Ashtech (*Z12-T Lab*)**
Temperature [ns/K] (k=1)	**L1=0.32 (0.02)** [286-308 K] **L2=0.31 (0.02)** [286-308 K]	**L1=0.09 (0.02)** [273-278 K] **L1=0.01 (0.02)** [278-313 K] **L2=0.02 (0.02)** [273-313 K]	**L1=0.10 (0.01)** [273-313 K] **L2=0.11 (0.01)** [273-313 K]
Humidity [ns/%] (k=1)	**L1=-0.004 (0.011)** [20-70 %] **L2=-0.001 (0.011)** [20-70 %]	**L1= 0.003 (0.011)** [20-70%] **L2= 0.002 (0.011)** [20-70%]	**L1= -0,001 (0.011)** [20-70%] **L2= -0,001 (0.011)** [20-70%]

The fluctuations observed at room temperature during the experiment in using the artificial reception method are about 0.4 ns/K. The equipment temperature study proves that these variations are due principally to the simulator with a linear temperature dependence of 0.32 ns/K. At room temperature, the Ashtech receiver is more sensitive to the temperature than the Septentrio receiver, where the thermal

dependence is 0.01 ns/K. The sensitivity of all equipment is very low to the variations of the humidity rate included between 20% and 70%.

The pseudo-range fluctuations due to the temperature variations are taken into account in the uncertainty budget in calculating the data standard deviation. It is, therefore, necessary to try to guarantee the best stability of the environment where the calibration takes place. These investigations prove it is important to precisely determine the temperature and the humidity rate during the calibration in order to compare the calibration results.

A simulator with more recent electronics, where the pseudo-ranges are produced by chips less sensitive to the temperature, will allow the reduction of the uncertainties due to thermal variations.

CONCLUSION

Since 2005, CNES has developed the absolute calibration, using artificial signals, which offers the possibility of calibrating independently each element of the time transfer system. It allows one to determine the electrical delay of the most of geodetic receivers used in time laboratories: Ashtech Z12-T, Septentrio PolaRx2, and Dicom GTR50 with an uncertainty of about 0.4 ns (k=1). The antenna cable delay can be calibrated with a 0.15 ns (k=1) uncertainty in the worst case. Even if the work of the antenna calibration setup must be continued, the first calibrations in using the transmission method give very impressive results, with an uncertainty of 0.45 ns (k=1). Currently, the overall uncertainty budget of the reception chain is about 0.64 ns (k=1). This error budget could still be reduced if the simulator uncertainty was not the dominant element in the receiver calibration.

The previous work has shown that, with a deviation of 1K, the pseudo-range fluctuations are about 0.4 ns/K. The study of the equipment behavior according to the temperature and the humidity proves that the dominant element is the thermal sensitivity of the simulator. Actually, there is an important correlation between the pseudo-ranges emitted by the Spirent 4760 simulator and the temperature. A previous study of the sensitivity of the simulator shows that this device has a linear temperature dependence of 0.32 (0.02) ns/K (k=1) for a room temperature range of 286 K to 308 K. The thermal sensibility measurement of the Ashtech Z12-T receiver presents a linear dependence of 0.10 (0.01) ns/K (k=1) for a range of 273 to 313 K. The temperature does not have a linear effect on the Septentrio L1 pseudo-ranges. The temperature influence is more strong between a range of 273 and 278 K, but is of 0.01 (0.01) ns/K of 278 to 313 K. The L2 pseudo-ranges have a linear temperature sensitivity of 0.02 (0.01) ns/K. The simulator and the studied receivers have a very low sensitivity to the humidity rate variations included between 20% and 70%. It is difficult to draw conclusions about the receiver delay variations according to time duration because the investigations were carried out over only 2 years. The variations observed seem correlated with the temperature rather than with the aging effect. It will necessary to perform this experiment on the long term and on different receivers in order to know if the receiver internal delay changes significantly after several years of utilization.

At the present time, the transmitting antenna used in the method in transmission has only been calibrated in transmission. In the future, the method in reflection must be put in operation to calibrate transmitting antennas with linear and circular polarization.

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